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Utilization of low temperature heat for environmentally friendly electricity production

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1 Motivation

Utilization of low grade heat is not feasible with conventional steam Rankine cycles due to undesirable properties of steam. Instead the organic Rankine cycle (ORC) is typically used, since it enables the choice of a working fluid, e.g. hydrocarbons, with desirable properties.

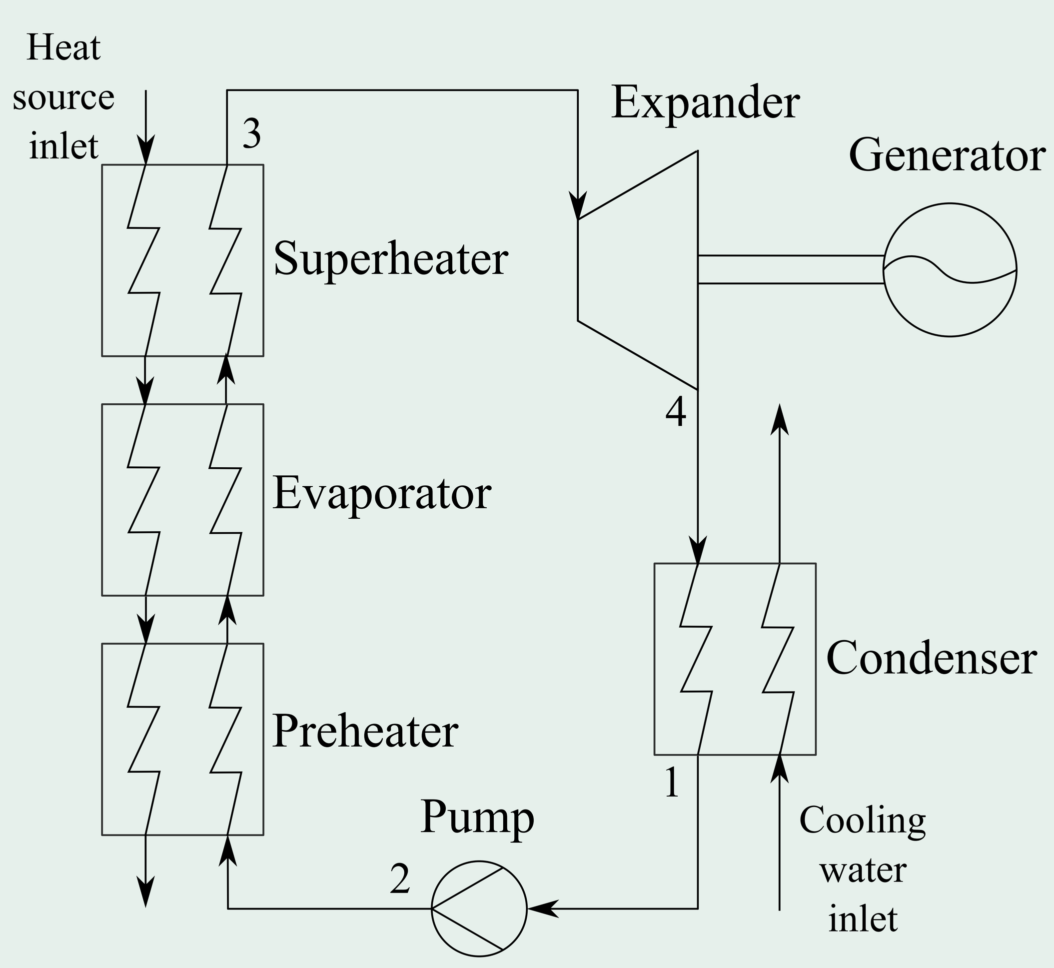

Figure 1: **A sketch of an organic Rankine cycle**

One of the key issues for improving the performance of ORCs is to optimize the heat transfer processes for adding and removing heat from the cycle, which can be achieved by employing mixed working fluids. A sketch of the ORC is shown in Fig. 1.

2 Optimization of working fluids

The aim of this project is to evaluate the feasibility of using mixtures as working fluids in ORCs considering both thermodynamics and economics.

The hydrocarbon mixture propane/isobutane has shown high thermodynamic performance in an ORC utilizing a low temperature heat source at T=120 °C [1]. The result of an optimization of propane/isobutane for different mole compositions is shown in Fig. 2.

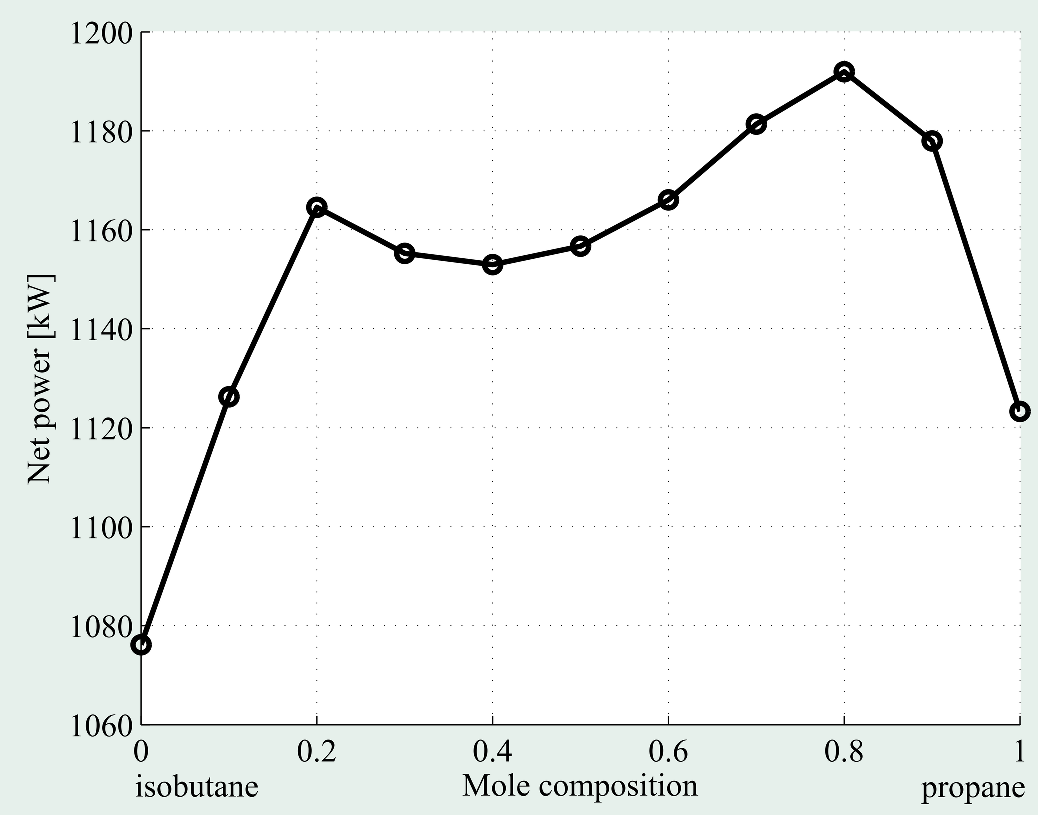

Figure 2: **Net power maximization for a propane/isobutane mixture**

The 0.8/0.2 propane/isobutane mixture achieves the highest net power output, which is 6.1 % higher than pure propane. The net power is generally higher for the mixtures, since the non-constant temperature during phase change enables a reduction in the temperature difference in the condenser and the evaporator resulting in a reduction of heat transfer losses.

3 Heat transfer analysis (condenser)

The heat ($\dot{Q}$) transferred in a heat exchanger can be expressed as:

$$\dot{Q} = UA\Delta T_m \quad (1)$$

where ΔT_m is the mean temperature difference between the heat exchanging streams, U is the overall heat transfer coefficient and A the heat transfer area.

The required heat transfer areas for mixtures are generally higher than those of pure fluids, due to the reduced temperature difference and a lower heat transfer coefficient. Table 1 shows a comparison of the net power and heat transfer parameters for isobutane, propane and two mixtures.

Table 1: **Net power and heat transfer parameters for isobutane, propane and two mixtures**

	$\dot{W}_{net}$ [kW]	ΔT_m [°C]	U [W/m^2-K]	A [m^2]
isobutane	1076	7.6	994	1526
0.5/0.5$_{mole}$	1157	6.5	948	1947
0.8/0.2$_{mole}$	1192	5.2	1040	2196
propane	1123	7.5	1394	1134

Figure 3 shows how the temperature difference between the working fluid and the cooling water is lower for the mixture compared to the pure fluid, resulting in higher performance and larger and more expensive heat exchangers.

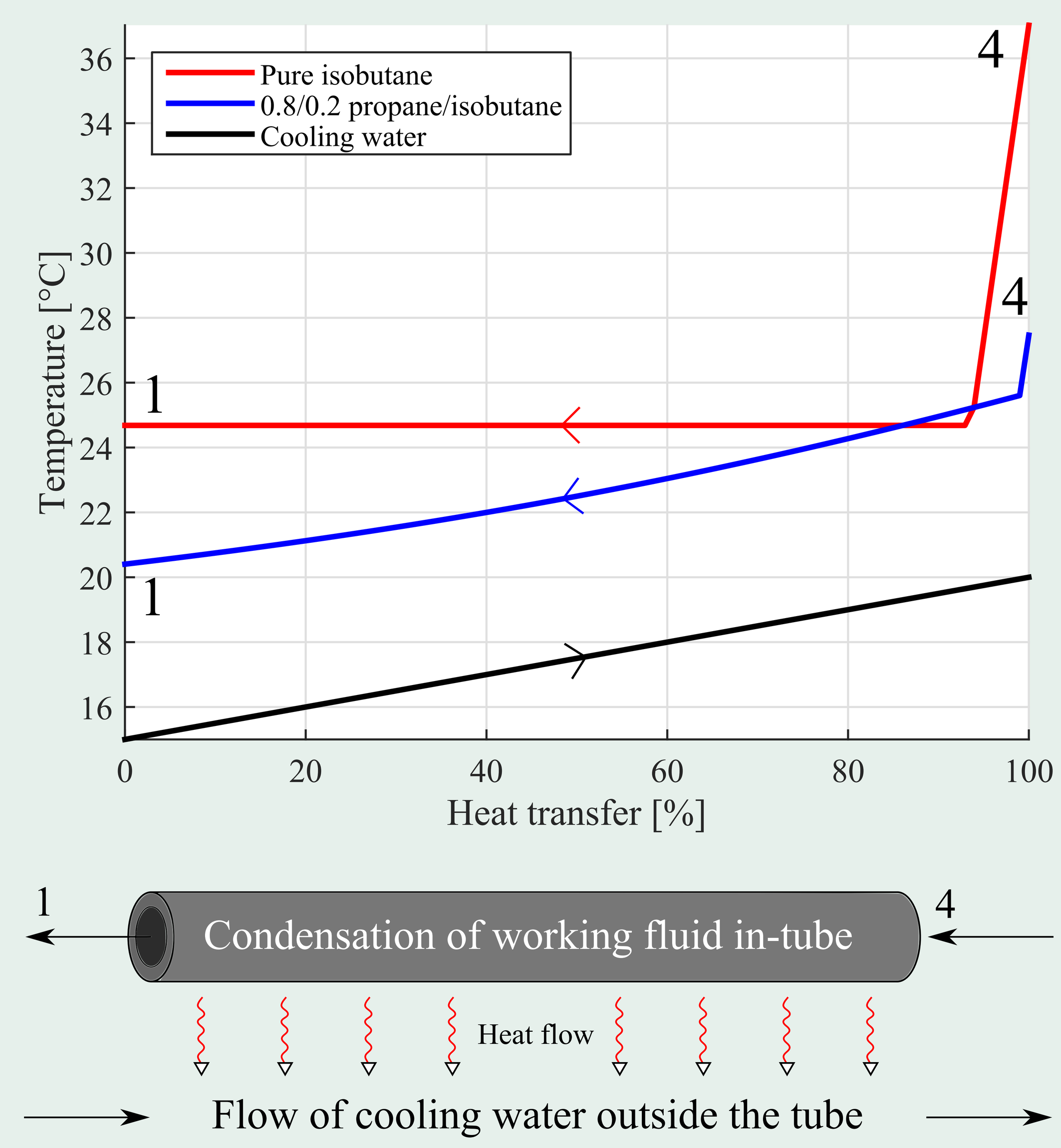

Figure 3: **A $\dot{Q}T$-diagram of condensation for isobutane and 0.8/0.2 propane/isobutane**

4 Conclusion

The use of mixed working fluids in ORCs has the potential of increasing the net power output when utilizing low temperature heat. On the other hand, the use of mixtures requires larger and more expensive heat exchangers compared to pure fluids. It is therefore necessary to carry out economic analyses in order to assess the feasibility of using mixed working fluids in ORCs.

5 References

[1] Andreasen J.G., Larsen U., Knudsen T., Pierobon L., Haglind F., Selection and optimization of pure and mixed working fluids for low grade heat utilization using organic Rankine cycles. Energy 2014;73:204-13.